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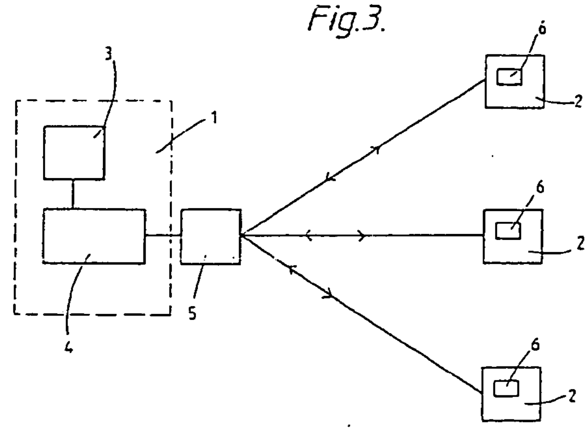
(54) **PCM signal coding.**

(57) A signal having a non-uniform probability density is processed for transmission in pulse code modulated form. The signal is quantised using conventional methods and the quantised signal then coded using a non-sequential coding scheme in which binary codewords for the quantisation levels are chosen in accordance with the probability of the quantisation levels and number of ON bits in the codewords. Quantisation levels of higher probability are assigned codewords with few ON bits.

An optical network embodying the present invention includes a central station1 having a master clock source 3. The central station1 is connected to a remote station 2 including signal processing means 6 arranged to process a signal for return transmission to the central station 1 by the method of the present invention.

Fig.3.

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**Description**

## P C M SIGNAL CODING

The present invention relates to Pulse Code Modulation (PCM) transmission techniques. It is particularly concerned with the problem of minimising the demands such techniques put upon the transmitter in the context of a system such as a passive optical network used for telephony.

In standard forms of coding for Pulse Code Modulation, such as the coding scheme recommended by CCITT for telephony, an analogue signal is divided into a number of quantisation levels (256 in the case of 8-bit coding) and each quantisation level assigned a binary codeword. The quantisation levels may be uniformly distributed over the amplitude range of the signal or alternatively a logarithmic distribution may be used. In either case the binary codewords are assigned sequentially to the quantisation levels so that, for example, in the CCITT 8-bit coding scheme quantisation levels 130, 131 and 132 are assigned binary codewords 1000 0001, 1000 00010 and 1000 0011. The first (i.e. most significant) bit of the codeword is used to denote the sign of the quantisation level.

According to a first aspect of the present invention a method of processing a signal having a non-uniform probability density for transmission in pulse code modulated form comprises quantising the signal and coding the quantised signal using a non-sequential coding scheme in which binary codewords for the quantisation levels are chosen in accordance with the probability of the quantisation levels and the number of ON bits in the codeword so that quantisation levels of higher probability are assigned code words with fewer On bits.

The present invention provides a coding scheme which minimises the power required to transmit signals such as speech or music which have non-uniform probability densities. The amplitude probability distribution of speech, for example, peaks around zero amplitude and decreases with increasing amplitude. Similarly after quantisation the most probable quantisation levels are those corresponding to the lowest amplitudes and the quantisation levels corresponding to increasing amplitudes have decreasing probabilities. The codeword which consumes the least power is all zeros, 0000 0000 in 8-bit coding, and that which consumes the most power is all ones, 1111 1111. Since the most likely quantisation level, i.e. zero for speech, will over a period of time occur most frequently it is allocated the codeword 0000 0000. The nearest eight levels are the next most likely and are therefore allocated codewords having just a signle ON bit, i.e. words taken from the set 0000 0001, 0000 0010, 0000 0100, ... 1000 0000. Such a coding scheme by matching the codewords requiring least power to the most frequently occurring quantisation levels effects a marked reduction in the time-averaged power required for transmission of the signal.

The advantages of using a method in accordance with the present invention are found to be particularly great for optical systems using sources such as semiconductor diode lasers. By enabling the transmitter in such a system to run cooler and place less demand on the power supply a significant increase in transmitter reliability is obtained. A further advantage is that with a method in accordance with the present invention near-end cross-talk levels are reduced. Intersymbol interference (ISI) is also reduced.

According to a second aspect of the present invention an optical network includes a central station having a master clock source and being connected to a remote station including signal processing means arranged to process a signal for return transmission to the central station by a method in accordance with the first aspect of the present invention.

In transmission from the central station to a remote station without its own clock it is necessary to code the signal using a conventional line code which allows a synchronous clock to be recovered at the remote station However for the return direction of transmission there is no need to re-transmit the clock since the master clock, with an appropriate phase shift, can be used to synchronise the regeneration of the signal received at the central station. Accordingly the processing of a signal for transmission along the return path to the central station is particularly appropriate for the use of a method in accordance with the first aspect of the present invention since the coding may be chosen simply to minimise the power requirements and there is no need for a conventional line code. Since a typical network will include many remote stations for each central station the advantages of a method which increases the reliability of the transmitters of the remote stations are particularly great.

The present invention is now described in detail with reference to the accompanying drawing in which:

Figure 1A and 1B are graphs illustrating probability distributions for signal amplitudes and the corresponding function for quantisation levels;

Figure 2 is a table listing a prior art coding scheme and a coding scheme in the accordance with the present invention; and,

Figure 3 is a diagram illustrating a network in accordance with the second aspect of the present invention.

A signal such as speech or music having a non-uniform probability distribution is quantised using conventional methods and a binary codeword assigned to each quantisation level. The codewords are transmitted in pulse code modulated forms using ON/OFF keying in a non-return-to-zero (NRZ) format.

In the preferred embodiment 8-bit codewords are used to code a total of 256 different quantisation levels. The binary codewords are grouped into subsets according to the number of ON bits, i.e. ones rather than zeros, present. An 8-bit binary code set has 9 subsets, ranging from all zeros to all ones. The number of members of each subset as given by the permutation formula is shown in table 1 below where (1/8) denotes

the subset of codewords having only one of the 8 bits equal to unity (2/8) denotes the subset of codewords having only two of the 8 bits equal to unity and so on.

TABLE 1

| SUBSET | NUMBER OF CODEWORDS |
|---|---|
| (0000 0000) | 1 |
| (1/8) | 8 |
| (2/8) | 28 |
| (3/8) | 56 |
| (4/8) | 70 |
| (5/8) | 56 |
| (6/8) | 28 |
| (7/8) | 8 |
| (1111 1111) | 1 |

The amplitude probability distribution of speech which is discussed in more detail below, is such that the most frequently occurring quantisation level is zero. The codeword requiring minimum power, 0000 0000 is therefore allocated to this level. The 8 codewords in the subset (1/8) are then assigned to the next most frequently occurring 8 quantisation levels and so on up to the subset (1111 1111), the codeword requiring the greatest power which is assigned to the quantisation level of lowest probability.

The 256 quantisation levels may be uniformly distributed over the amplitude range of interest or, in the case of the A law companding commonly used for speech a logarithmic distribution may be used which matches more closely the sensitivity of the ear. The piecewise linear approximation to the A law as recommended by the CCITT is shown in figure 1A for input amplitudes in the range 0-1 V. A symmetrical function is used for negative input levels.

The amplitude probability distribution of speech is represented by a gamma function (also shown in figure 1A,)

$P(x) = (k/2\Gamma(\ell))\ (kx)^{\ell-1}e^{-kx}$

where x is the instantaneous r.m.s. amplitude and $\ell$ is a parameter and $k = [\ell(\ell+1)]^{1/2}$. This function which peaks around 0 and is small at high levels. is discussed in detail in the text "Telecommunications By Speech", author D L Richards, published by Butterworth. If uniform quantising is used for speech then the probability distribution function (PDF) given in figure 1A would also represent the probability of any quantisation interval occurring, and appropriate code allocations could readily be made. For the case of particular interest where companding is used the PDF for the various quantisation intervals must be derived by considering the mapping of the gamma function through the piecewise linear approximation to the A law. For simplicity this mapping has also been performed graphically for each linear segment and the resultant histogram is shown in figure 1B. This PDF also peaks at low input levels. There is a secondary maximum at input amplitudes around +/- 0.5 which could affect the optimum choice of codewords so that the allocations for uniform and companded quantising would differ. However, since the peak is small and its position would vary for loud and quiet speakers, it may conveniently be neglected.

Since both uniform and companded quantising give rise to PDFs which peak at low input amplitudes the codeword allocations range from the minimum power codes near zero through to the highest power codes (7/8) and (1111 1111) at the extremes.

The table of Figure 2 shows one possible power minimising coding scheme employing symmetry for a selection of 256 quantising levels. This is compared with the present CCITT recommendations for speech transmission. Gaps are left in the table to separate the subsets of numbers of ON bits per word. These subsets are divided between the positive and negative quantisation levels which split at quantisation levels 128/129. Dotted lines show where the table is incomplete.

When no speech is present at the input to the encoder, random noise will cause the quantiser to waver between levels 128 and 129, assuming the noise is at a low level. Under this condition it is advantageous to

represent both levels by the codeword 0000 0000. This then prevents power being transmitted during, for example, the pauses while someone using a telephone system is listening to received speech. To avoid ambiguity at the decoder the same effect could be achieved by applying a DC offset equal to half a quantising interval in the positive sense at the input to the encoder. There is then no ambiguity at the encoder output when no signal is present at the input.

An optical network employing the method of the present invention is shown diagramatically in figure 3. A time division multiple access (TDMA) network includes a central station1 lined to remote stations 2. The central station includes a master clock 3, a transceiver 4 which includes an optical source such as a semi-conductor diode laser and signal processing means, and is connected to the remote stations via a passive power divider 5. Digital signals are transmitted from the central station 1 to the remote stations 2 using conventional line coding techniques. Each remote station extracts a clock from the incoming signal which it uses to synchronously demultiplex the channels it is to receive. In the return direction a time division multiplex is formed by interleaving data from each of the remote stations 2. For the return direction of transmission there is no need to retransmit the clock since the network is now synchronous. The transceivers 6 of the remote stations 2 therefore include, in addition to optical sources, signal processing means arranged to operate in accordance with the method of the first aspect of this invention. The signal for return transmission is encoded using a power-minimising coding scheme and without a conventional line code. As a result the optical source in each remote station 2 runs cooler and places less demand upon the power supply. This method is found to increase significantly the reliability of the remote stations and so to enhance that of the network as a whole.

## Claims

1. A method of processing a signal having a non-uniform probability density for transmission in pulse code modulated form comprising quantising the signal and coding the quantised signal using a non-sequential coding scheme in which binary codewords for the quantisation levels are chosen in accordance with the probability of the quantisation levels and the number of ON bits in the codeword so that quantisation levels of higher probability are assigned codewords with few ON bits.

2. A method according to claim 1, in which the probability density decreases with increasing amplitude and the one positive and one negative quantisation levels of least amplitude are both assigned codewords having no ON Bits.

3. A method according to claim 1 or 2, in which the coded signal is transmitted using a semiconductor optical source.

4. An optical network including a central station have a master clock source and being connected to a remote station including signal processing means arranged to process a signal for return transmission to the central station by a method in accordance with any one of the preceding claims.

5. A method of processing a signal substantially as described with reference to the accompanying drawings.

6. An optical network substantially as described with reference to the accompanying drawings.

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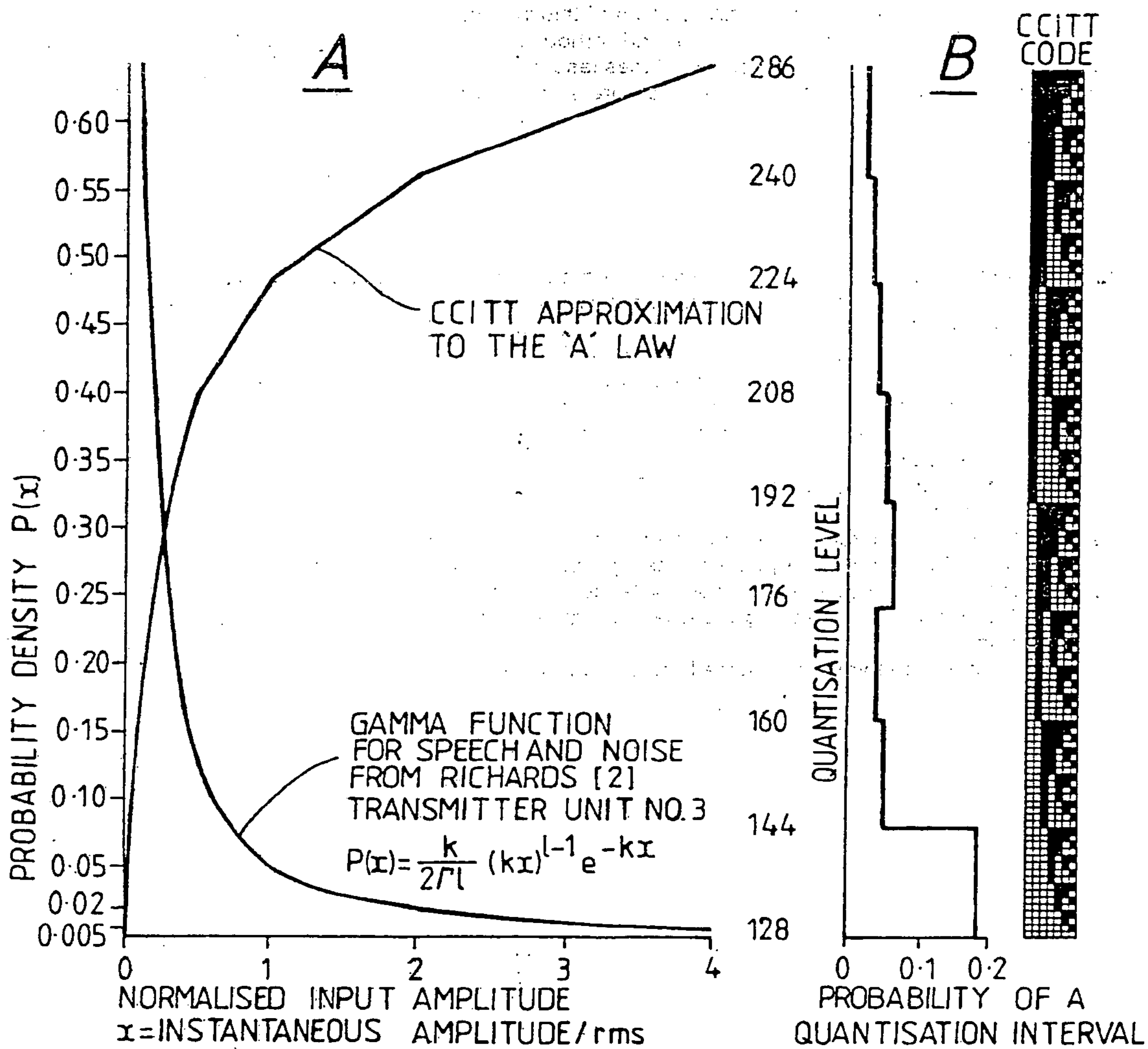
Fig.1.

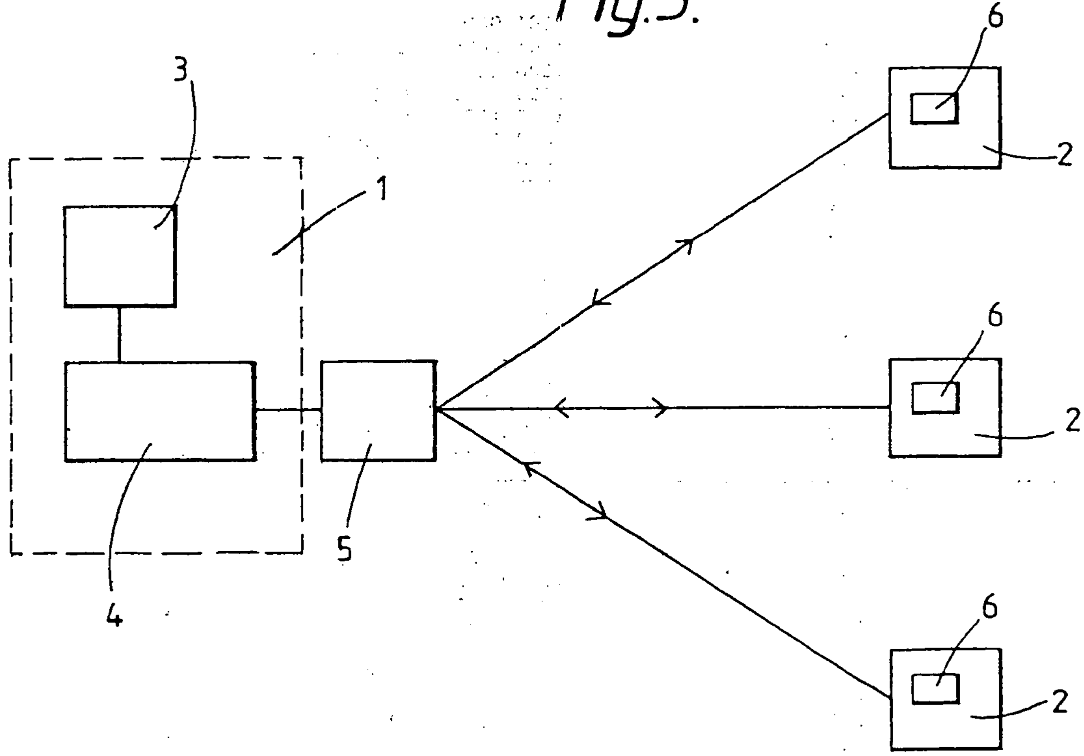


# Fig. 2.

Table 1

| Quantisation level | CCITT (PRIOR ART) | Min.Power | |
|---|---|---|---|
| 256 | 1111 1111 | 1111 1111 | |
| 255 | 1111 1110 | 1111 1110 | |
| 254 | 1111 1101 | 1111 1101 | |
| 253 | 1111 1100 | 1111 1011 | |
| 252 | 1111 1011 | 1111 0111 | |
| 251 | 1111 1010 | 1111 1100 | |
| : | : : | : : | |
| 147 | 1001 0010 | 1110 0000 | |
| 146 | 1001 0001 | 0001 1000 | |
| 145 | 1001 0000 | 0011 0000 | |
| 144 | 1000 1111 | 0100 0001 | |
| 143 | 1000 1110 | 0100 0010 | |
| 142 | 1000 1101 | 0100 0100 | |
| 141 | 1000 1100 | 0100 1000 | |
| 140 | 1000 1011 | 0101 0000 | |
| 139 | 1000 1010 | 0110 0000 | |
| 138 | 1000 1001 | 1000 0010 | |
| 137 | 1000 1000 | 1000 0100 | |
| 136 | 1000 0111 | 1000 1000 | |
| 135 | 1000 0110 | 1001 0000 | |
| 134 | 1000 0101 | 1010 0000 | |
| 133 | 1000 0100 | 1100 0000 | |
| 132 | 1000 0011 | 1000 0000 | |
| 131 | 1000 0010 | 0100 0000 | |
| 130 | 1000 0001 | 0010 0000 | |
| 129 | 1000 0000 | 0001 0000 | positive input levels |
| 128 | 0000 0000 | 0000 0000 | negative input levels |
| 127 | 0000 0001 | 0000 0001 | |
| 126 | 0000 0010 | 0000 0010 | |
| 125 | 0000 0011 | 0000 0100 | |
| 124 | 0000 0100 | 0000 1000 | |
| 123 | 0000 0101 | 0000 0011 | |
| 122 | 0000 0111 | 0000 0101 | |
| 121 | 0000 1000 | 0000 1001 | |
| 120 | 0000 1001 | 0001 0001 | |
| 119 | 0000 1010 | 0010 0001 | |
| 118 | 0000 1011 | 0100 0001 | |
| 117 | 0000 1100 | 0000 0110 | |
| 116 | 0000 1101 | 0000 1010 | |
| 115 | 0000 1110 | 0001 0010 | |
| 114 | 0000 1111 | 0010 0010 | |
| 113 | 0001 0000 | 0100 0010 | |
| 112 | 0001 0001 | 1000 0010 | |
| 111 | 0001 0010 | 0000 1100 | |
| 110 | 0001 0011 | 1000 0001 | |
| 109 | 0001 0101 | 0000 0111 | |
| : | : : | : : | |
| 001 | 0111 1111 | 0111 1111 | |

Fig.3.



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# EUROPEAN SEARCH REPORT

Application Number

EP 88 30 6675

| Category | DOCUMENTS CONSIDERED TO BE RELEVANT<br>Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (Int. Cl.4) |
|---|---|---|---|
| Y | IBM TECHNICAL DISCLOSURE BULLETIN, vol. 28, no. 10, March 1986, pages 4440-4441, New York, US; "Grouop encoding method for infrared communication"<br>* Page 4441, lines 10-17 *<br>--- | 1,3,5 | H 03 M 7/00<br>H 04 B 9/00<br>H 04 B 14/04 |
| Y | G. HELD: "Data compression", 1983, John Wiley & Sons, Chichester, GB<br>* Page 57, lines 15-22 *<br>--- | 1,3,5 | |
| A | EP-A-0 103 248 (ROBERT BOSCH)<br>* Figure 3; page 7, lines 18-33 *<br>--- | 1 | |
| A | US-A-4 667 337 (FLETCHER)<br>* Column 2, line 60 - column 3, line 11 *<br>--- | 1 | |
| A | US-A-4 027 153 (KÄCH)<br>* Figure 1; column 2, lines 15-34; column 3, lines 1-3 *<br>--- | 3 | TECHNICAL FIELDS SEARCHED (Int. Cl.4) |
| A | IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, vol. SAC-4, no. 9, December 1986, pages 1484-1493, IEEE, New York, US; P.R. PRUCNAL et al.: "Ultrafast all-optical synchronous multiple access fiber networks"<br>* Figure 1; page 1484, right-hand column, line 41 - page 1485, left-hand column, line 9 *<br>----- | 4,6 | H 03 M<br>H 04 B<br>H 03 K<br>H 04 L |

The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| THE HAGUE | 21-10-1988 | FEUER F.S. |

CATEGORY OF CITED DOCUMENTS

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